Impact of Energy Transition on Profitability of Different Zero-Carbon Generation Technologies in Internationally Integrated Electricity Markets

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Overview

In order to reduce the absolute levels of carbon emissions, the nature of energy systems has to change dramatically. This is the reason governments are promoting the development and use of renewable energy sources like solar PV, wind turbines, hydropower and biomass. Despite these policies, the growth in renewable energy will likely not be sufficient to reduce carbon emissions to the extent required to meet climate targets. Therefore, the attention is increasingly also going to another non-carbon energy source, which is nuclear power. While nuclear power plants, solar PV installations, and wind turbines may differ significantly from a technical standpoint, they share a key economic characteristic that sets them apart from fossil-fuel plants. Traditional fossil-fuel power plants incur costs for every unit of electricity generated, depending on factors like fuel prices and conversion efficiency. In contrast, nuclear power, solar PV and wind turbines have much less additional costs when they generate electricity. This means that the fixed costs of these types of power plants constitute the major part of their total costs. This has a number of consequences related to the profitability of these generation technologies.

Methods

To evaluate the impact of the energy transition on the profitability of various zero-carbon power generation technologies, our approach encompasses several steps. Firstly, we develop a short-term partial equilibrium model, designed to mimic the dynamics of a power market. The mathematical model is based on Li and Mulder (2021) and Veenstra and Mulder (2024). Our model calibration is centered on the electricity markets of the North-West European countries. By simulating hourly market dynamics, we determine the electricity prices captured by different technologies and their corresponding production levels. Subsequently, we calculate the Levelized Cost of Electricity (LCOE) and subsidies required to achieve break-even investments (based on the Net Present Value, NPV). This assessment is conducted for different market shares of solar PV, onshore wind, and offshore wind and different amounts of battery capacity to show the effects of the energy transition on the profitability of these technologies.

Our contributions to the literature is that we not only investigate the effects of increasing shares of renewables on capacity factors and capture prices, but also examine how these dynamics impact investment metrics such as the LCOE and NPV. Secondly, where existing studies only consider the effects of adding more renewables on the renewables themselves, we also consider the effects on the profitability of nuclear power, an alternative low-carbon electricity generation technology. In addition, we control for the effects of international integration by modelling the Northwest European electricity market simulataneously. While we also include the impact of flexible sources, in particular batteries. Methodologically, we use an electricity market model that differs from models that minimize generation costs under fixed demand levels. Instead, we treat installed capacities of solar, wind and nuclear as exogenous and incorporate price-responsive demand. This exogenous assumption of capacities is often in line with energy policies, while the price-responding demand enhances the representation of demand side flexibility. We analyse the sensitivity of the results to different assumptions regarding the overnight costs of the various technologies.

Results

We find that an increasing share of renewables leads to lower overall electricity prices. However, a closer examination reveals nuanced effects: solar and wind capture prices decrease compared to the mean electricity price. In contrast, nuclear capture prices increase, as these plants can also produce during periods of scarcity. The increasing share of renewables also impacts capacity factors, as more hours occur where available solar and wind energy can satisfy demand. The capacity factors of nuclear and solar PV are affected most, as nuclear power plants have higher generation costs than solar and wind, and the availability of solar energy is much less evenly distributed than the availability of wind energy.

We also find that the Levelized Cost of Electricity (LCOE) of all technologies increases when more renewables are installed. However, due to the different effects on production, the LCOE of wind energy is less sensitive than the LCOE of solar and nuclear power. When we calculate the required subsidy that is needed to make the Net Present Value (NPV) of new investments non-zero, we see that more subsidy is required in an electricity market dominated by renewables. The required subsidy of solar PV is most sensitive to these changes, while the required subsidy of nuclear power increases least fast due to the relatively high capture price. It also appears that nuclear power plants benefit more from higher gas or carbon prices than wind turbines and solar PV. Because of their high availability factor, nuclear power plants are able to produce electricity when gas-fired power plants set the electricity price, and hence, they experience higher electricity prices when the costs of gas-fired power plants increase. The results appear also to be robust for various values of the discount rate, and do not change substantially when assumptions on energy storage and international trade are changed.

Conclusions

Our findings may form an input for the ongoing societal conversation surrounding future electricity systems, but it’s important to recognize that our analysis primarily focuses on the profitability of various technologies. To fully inform this debate, a comprehensive understanding of other critical aspects, such as safety issues, environmental impact, and societal acceptance of different energy generation methods, is essential. Furthermore, our study did not encompass system-wide effects, like the implications for grid investments, which significantly shape the future energy landscape. Nonetheless, our results provide valuable insights for policymakers, revealing how the costs and advantages of different technologies are depend on the electricity system they are placed in. Notably, our research suggests that installing too many solar PV installations could potentially undermine their economic viability, while investments in wind energy and nuclear power appear to be promising choices in electricity systems with many renewables. These conclusions are partly mitigated when there are higher shares of flexible sources such as batteries and higher degrees of international integration and/or when the overnight costs of renewable sources decline strongly in comparison to the ones of nuclear power plants.

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